Use of Forests and Wood Products to Mitigate Climate Change

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1 Introduction

The increased concentrations of greenhouse gases in the atmosphere are one of the most severe current environmental problems. The annual atmospheric increase of carbon is estimated to be 3.2 Pg (IPCC, 2001, p. 190). In comparison, the annual harvest of roundwood is about 3.5 billion cubic meters (FAO, 2006) and contains approximately 0.8 Pg carbon in roundwood (assuming 0.23 Mg C/m^3) and is, hence, significant also for the global carbon balance. The estimated amount of carbon in forested areas is approximately 650–1,200 Pg (House et al., 2003; Grace, 2004; FAO, 2006), most of which is located in forest soils. Recent aboveground biomass estimates are between 257 Pg (Kauppi, 2003) and 359 Pg (IPCC, 2001). Given the large amounts, even a small proportional change is influential.

Industrial use of wood fulfills a share of the material needs of the human population. Environmental policies can influence the consumption of alternative materials. Given the large mount of global wood utilization, it is relevant to ask what are the impacts of wood use on the global carbon cycle. Should more wood be consumed to replace materials that require more fossil energy or should less wood be consumed to increase the forest carbon sink?

Wood carbon has several, partly competing, functions in climate change mitigation: (1) wood carbon can be stored into forest ecosystems by different silvicultural strategies; (2) wood carbon can be stored as products in use or in landfills; (3) wood products can be used for materials that substitute other materials with higher fossil emissions; (4) wood is used for bioenergy in different stages of the life cycle.

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When wood is used for materials and energy, other materials and energy are substituted. Use of these substitutes in place of wood would in most cases cause larger fossil emissions. Valsta et al. (2005) have preliminary estimated that, given the current materials use, the global potentially avoided emissions due to wood use are around 0.4 Pg carbon. At the same time, the utilization of forest resources and land-use change cause a release of carbon of 1.1 Pg, mostly due to deforestation in the tropical areas (FAO, 2006). The regional patterns of these changes are shown in Fig. 1. The boreal and temperate forest regions exhibit an increase of biomass while a strong decline takes place in the tropical areas.

The global average annual forest biomass decline rate has slightly increased from 0.37% to 0.40% for 1990–2000 and 2000–2005, respectively. The net woody biomass increase in the temperate and boreal forest regions of the world was estimated to be 0.88 Pg/year in 2000 (FAO, 2001) and in 2005 down to 0.30 Pg/year. An even lower estimate, 0.21 Pg/year into living biomass in the Northern Hemisphere, is given by Goodale et al. (2002). A recent study by Kauppi et al. (2006) rather suggests an increasing trend in biomass accumulation into boreal and temperate forests.

According to FAO's Global Forest Resources Assessment 2005 (FAO, 2006), the global wood removals (harvests) have remained at an approximately constant level from 1990 to 2005 at 3 billion cubic meters. Of the removals, 60% were industrial

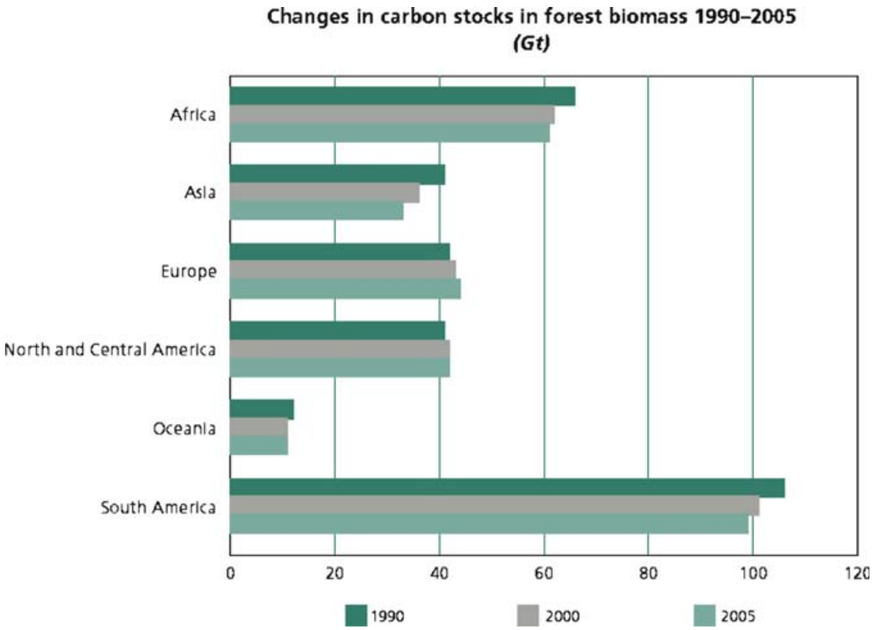

Fig. 1 Changes in regional forest biomass (FAO, 2006)

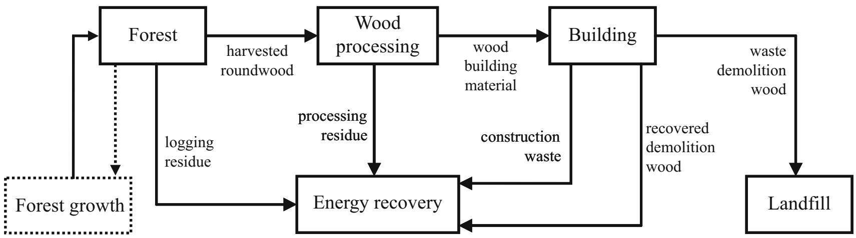

Fig. 2 Carbon flows in an integrated analysis covering forest dynamics and the wood product life cycle (Modified from Gustavsson et al., 2006)

roundwood and 40% fuelwood. However, FAOSTAT statistics (2006) report a 500 million cubic meters higher fuelwood use and the resulting total roundwood removals became 3,490 million cubic meters for 2005 with industrial roundwood and fuelwood shares of 48% and 52%, respectively.

To evaluate the flow of carbon through wood use, life-cycle analyses are required. Most life-cycle analysis studies include the wood flow from harvest to demolition. As such, they do not address the dynamic nature of forest carbon pools: the growth of forest (the flow of carbon from atmosphere into forest) dynamically depends on the size of the forest carbon pool (Fig. 2). Additionally, this relationship is nonlinear so that an increase of forest carbon pool first increases the growth but as crowding increases growth decreases. This review addresses the need for integrated analysis where forest dynamics and wood use impacts are jointly analyzed.

Most of the world's managed forests are under so called even-aged management or rotation forestry. We assume here that such forests are managed with sustained yield and regeneration of the cut areas. In these forests, an increase in carbon pools can result from either an increase in rotation length or an increase of growing density. The former is achieved just by postponing the final harvest. The latter requires either reduced thinnings or more efficient regeneration and young stand management. Integrated studies can be made where the impacts of wood use on both the forest dynamics and material life cycle are addressed. In the following, we analyze three such studies and synthesize knowledge based on them.

2 Case Studies

The case studies that we review address the impacts of forests and wood products in an integrated way. The studies have adopted different methods to analyze the question and they also have different temporal and spatial characteristics. Two of them refer to northern Europe and one to North America.

2.1 CORRIM Study (Perez-Garcia et al., 2005a)

The CORRIM studies build on a large body of life-cycle analyses of different wood products (Perez-Garcia et al., 2005b), analyzed in the context of residential construction. They build a carbon and emissions accounting model where three carbon pools were identified: carbon in forest, carbon in forest products, and carbon associated with energy displacement and avoided emissions. Starting from stand establishment, these carbon pools area tracked over time as the forest grows, wood gets harvested and processed, and products are used to build residential houses. Pulp and paper manufacturing was not considered. To evaluate the avoided emissions due to wood use, functionally equal residential houses were compared with wood vs. concrete or steel frames in structures. The wooden houses contained 1.97 times more wood than the alternative steel-framed house (Lippke et al., 2004).

To be able to compare alternative buildings, the CORRIM studies covered a detailed analysis of the production and use of wood building materials (lumber, plywood, OSB, glulam, laminated veneer lumber and I-joists). The SimaPro software was used to construct life-cycle inventories for each product. These product data were incorporated into the Athena Environmental Impact Estimator model which also contains data about alternative construction materials.

The emissions accounted for included those from silvicultural operations, harvesting stands, and manufacturing wood products. The additional biofuel substituted for natural gas.

The environmental performance of alternative materials was compared using several indices: embodied energy, global warming potential, air emission index, water emission index, and amount of solid vaste. The global warming potentials of steel vs. wood and concrete vs. wood buildings were 26% and 31% larger, respectively (Lippke et al., 2004).

To analyse the carbon dynamics over time, a combined forest, products, and substitution carbon model was build (Manriquez, 2002). Forest development was projected using the LMS system (Oliver, 1992). It accounted for tree canopies, stems, roots, litter and snags. Wood products were divided into short-term and long-term products. Different carbon pools had individual decay rates that were applied in the simulation. Four management scenarios were formed: managed Douglas fir forest with 45, 80 and 120 years rotations, and a no-harvest scenario for 165 years (the 80-year regime is shown as an example in Fig. 3). Simulations were carried out for a total time of 165 years.

Comparisons between rotation ages showed two main characteristics. For the combined carbon pools of forest and products, longer rotations increased the carbon pools, at least to the age of 165 years. Contrary, when energy and material substitution were added, the shorter the rotation, the greater the cumulative mitigation impact of the whole (Fig. 4).

With the assumption that a given house will be built with either wood frame or alternative frame, the global warming potentials (GWP) can be compared. The global warming potentials were 37,047 and 46,826 kg for wood and steel frame houses,

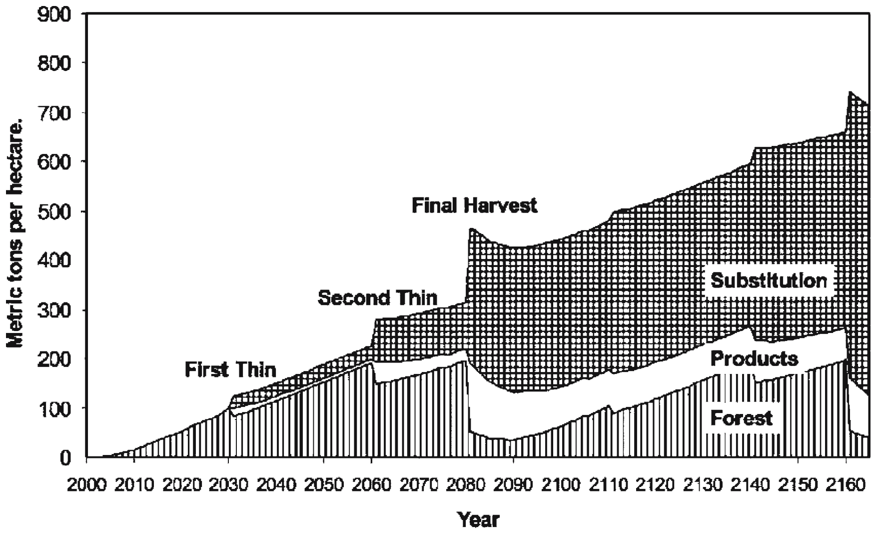

Fig. 3 Carbon in the forest and product pools with concrete substitution for the 80-year rotation (from Lippke et al., 2004)

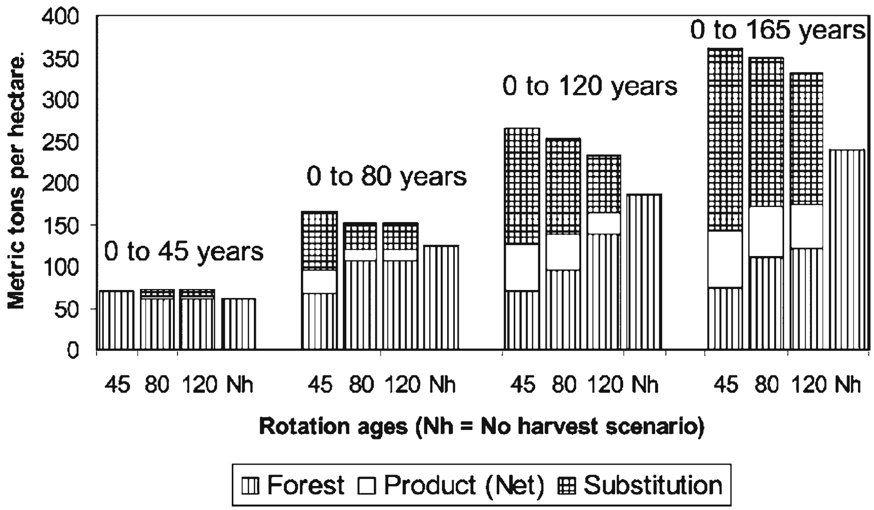

Fig. 4 Average carbon per year in forest, product, and concrete substitution pools for different rotations and simulation times

respectively (ratio 1.26) (Lippke et al., 2004). These amounts can be made relative to the carbon in wood employed in houses (6,496 and 3,298 kg, respectively). The incremental wood carbon used in a wooden house reduced the global warming potential at the rate of – 0.83 metric tons of GWP in C equivalents units for each additional metric ton of wood C in wood.

2.2 Pingoud et al., 2006

The study (Pingoud et al., 2006) examines the relationships between carbon pools in the forest and wood products use. The study compared present silvicultural guidelines in Finland to modifications that would change the climate change mitigation impact of forests. Silvicultural changes included increases of rotation length and of growing density. These alternatives have two kinds of impacts: (1) they affect wood yield and consequently the amounts of wood products; (2) they change forest carbon sequestration and the steady state carbon pool.

The study is based on a steady state analysis of fully regulated forests (also known as normal forests) with alternative silvicultural practices. The annual wood yield is constant but different in each alternative. The analysis employs a baseline alternative where a given silviculture yields corresponding amounts of wood products. On the consumption side these products are used to fulfill a functional need, in this case housing, pulp and paper manufacture and bioenergy. To compare the alternatives to the baseline, it was assumed that the same material function had to be fulfilled. For sawtimber it was assumed that the number of houses was fixed in all the alternatives but the share of wooden houses was dependent on the sawtimber yield. With a modified silviculture, the sawtimber yield is, in our simulations, increased and, consequently, more houses with wooden frames are being built. For the same simulations pulpwood yields often decreased but not always. Note that also concrete framed houses utilize significant amounts of wood products. The change in building materials led to a change in net fossil carbon emissions according to the energy usage of different building materials and to the om pulp and paper manufacture are based on the study by Pingoud and Lehtilä (2002) substitution of fossil fuels by bioenergy originated in energy wood from forest, residues from wood processing, and construction and demolition waste from housing. The data for emissions and material use are from Gustavsson et al. (2006). The data on fossil carbon emissions from pulp and paper manufacture are based on the study by Pingoud and Lehtilä (2002).

Silviculture scenarios were based on the silvicultural guidelines issued in Finland (Hyvän metsänhoidon suositukset, 2001), as realized in the Motti simulation software (Hynynen et al., 2005). In addition to the baseline, modified silvicultural regimes were:

- Increase of rotation by 20 or 40 years
- Increase of rotation by 20 or 40 years and increase of basal area by $4\,m^2/ha$
- Precommercial thinning of energy wood

Basal area increase was defined as an equal change in basal area before and after thinning, causing the thinning to be postponed. Comparing the alternatives we observed that at first, increasing forest biomass lead to increased growth and yield of wood products. When the biomass was further increased, growth began to decline and the wood product yield, as well.

Fully regulated forests were constructed that employed the given regimes, one each. The resulting yields of sawtimber were directed to produce sawn wood and wood-based panels to be used in house construction. For pulpwood two consumption

sub-scenarios were considered both meeting the condition of the same material function: (1) pulp and paper production was constant in each alternative; in case of excess pulpwood yield it was utilized as bionergy to substitute coal, (2) pulp and paper production varied with pulpwood yield, but in case of paper deficit an emission-free substitute (e.g. electronic media) was assumed be applied on the consumption side to fulfill the same material function. From Scots pine chemical paper was manufactured, and from Norway spruce mechanical paper, both having different emission profiles. Analyses were carried out for Scots pine and Norway spruce forests, separately. Only the results for Norway spruce are presented here.

When wood materials are directed to different uses, they affect the fossil emissions, relative to the baseline. The fuel replaced by bioenergy was assumed to be coal, and oil was assumed to be used in production of building materials. The avoided emissions due to an increase in wood use can be compared to the carbon in the harvested biomass. In the article by Pingoud et al. (2006) a marginal fossil carbon substitution factor was introduced as relating the fossil C emission reductions (with respect to a baseline) to the additional wood biomass use (with respect to the wood yield in baseline). This gave relative substitution coefficients which indicate how much fossil emissions are changed for each ton of additional wood harvested to different uses (for Norway spruce):

Sawtimber (Swedish multi-story apartment house)	–2.05
Sawtimber (Finnish multi-story apartment house)	–1.31
Pulpwood (pulp & paper production constant, excess wood for bioenergy)	–0.89
Pulpwood (function constant, paper deficit replaced by electr. media)	0.48
Energywood (for bionergy to replace coal)	–0.89

Each silvilcultural regime produced a given amount of sawtimber, pulpwood, and energy wood. When their emissions are totalled, we can compute the average emissions per year and hectare for each regime. For Norway spruce, when applying the Swedish building data, increases in rotation and basal area lead to decreases in emissions (Fig. 5). The change was somewhat larger due to basal area change (defined as basal area before and after thinning), compared to rotation change. The positive substitution factor of pulpwood is related to sub-scenario (2) above. Emissions would be increased with increased pulpwood use in this latter case – or reduced by decreased consumption – because the substitute would cause less emissions than pulp and paper production. This is seen in the effects due to basal area change which increased the growth rate of stands at thinning ages.

The silvicultural regimes also differed in terms of carbon pools in the forest and products. Although there is no evident way of comparing the benefit from a change in carbon pools with the change in annual emission, we portray them side by side by computing the present value in physical terms of the tons of avoided emissions (cf. Hoen & Solberg, 1994). Figure 6 shows this comparison for the case where excess pulpwood is directed into pulping. It can be seen that the present value of emission reductions is generally slightly smaller than the change in carbon pools for Norway spruce.

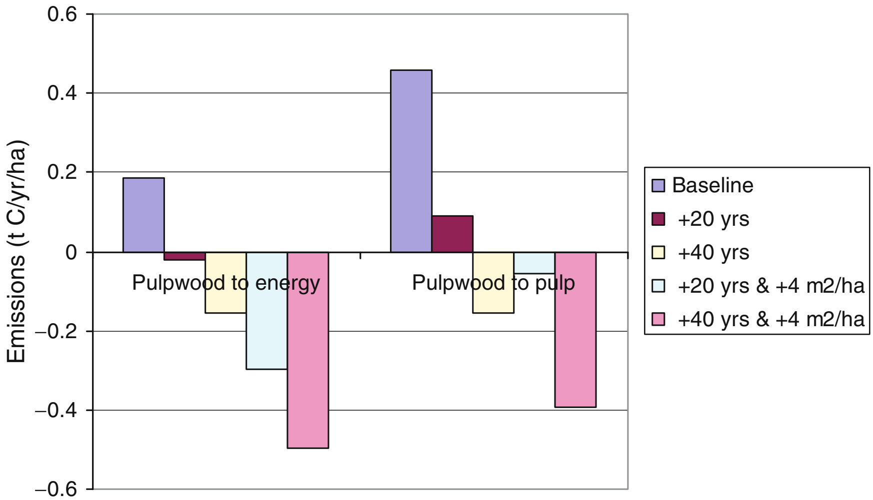

Fig. 5 Total emissions from wood utilization based on silvicultural regimes for Norway spruce, Swedish building

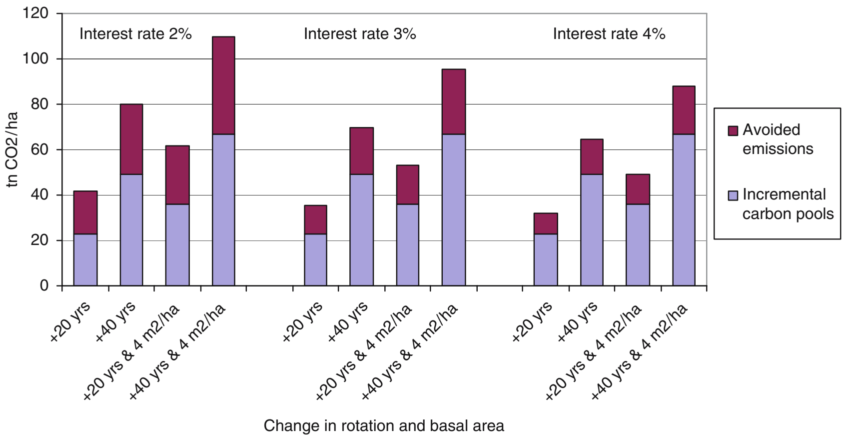

Fig. 6 Changes in the present value of discounted emissions and steady state carbon pools due to changes in rotation and stand basal area before and after thinning, Norway spruce

Compared to present silvicultural guidelines in Finland, an increase in rotation and growing density increased carbon pools in forests and wood products. They also increased the avoided emissions for Norway spruce because more wood was available for sawtimber to substitute for concrete framed houses. This result is naturally conditioned to the fixed amount of house construction. It should be noted additionally, that further increases of rotation or growing density may not show further increases in emissions reductions because forest growth might not increase any more.

2.3 GAYA-J/C Model (Petersen et al., 2004, 2005)

While the two previous studies were based on stand-level and conceptual fully-regulated forest level analyses, the GAYA/JC model operated on forest or regional level. The analyses reviewed here pertain a large forest area in Southern Norway. The model connects forest planning with climate change mitigation impacts based on forest and forest product use.

The basis of the model is a forest area planning model that utilizes forest inventory data, whole-stand growth models and forest management optimization using linear programming. Forest management activities in the model are

- No treatment
- Release thinning
- Thinning
- Fertilization
- Clear cut
- Seed tree cut
- Planting

Each of these activities have many alternatives defined, and the model solutions contain optimal harvests of pulpwood and sawtimber over time in the forest area analyzed. The carbon accounting module is comprehensive and includes trees, dead wood, litter, harvest residues, soil, wood products, and energy and material substitution. Carbon related benefits are computed as the present value of sinks (forests and wood products) and emissions reductions. Wood use is divided into energy, sawtimber, and pulp and paper.

Both economic variables and climate change mitigation impacts can be specified as objectives for the analyses. Additionally, different variables can be treated as constraints, which enables trade-off analyses between the goal variable and constraints, such as NPV of timber harvests vs. mitigation impacts. In addition to aggregate variables, the model solution identifies the optimal management regimes for forest stands (or for classes of stands) over time for the specified objective function and constraints. The model also operates with various discount rates (from 0 p.a. and upwards) reflecting the weight one puts on when in time benefits and costs occur.

The case study about the Hedmark County has the following characteristics:

- Productive forest land 1.3 million hectares
- Data from 2,207 sample plots
- Forty-seven percent Scots pine, 41% Norway spruce, 8% broadleaves in forest inventory
- Twenty-eight percent of area is in the oldest age class
- The annual actual harvest has been 2.3 million cubic meters
- The model runs span 12 planning periods, 10 years each

The starting points of the analyses were two optimization problems and their solutions: maximization of net present value of timber harvests, and maximization of

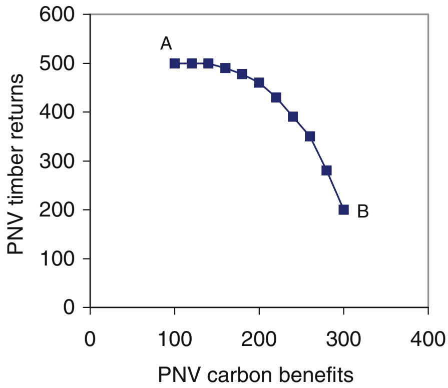

Fig. 7 Trade-off between timber returns and carbon benefits

the present value of carbon benefits (sequestration and substitution). These two solutions provided the extremes for a trade-off analysis. Intermediate optimum solutions were generated by maximizing the present value of timber returns subject to 10%…90% range of carbon benefits (their present value) (Fig. 7). When the weight of carbon benefits was increased (going from point A to point B), the frequency of harvest activities decreased leading to fewer thinnings, fewer release thinnings, and longer rotations. At the same time, more of the regenerated area was planted as opposed to natural regeneration. Average standing volume of the forest area increased very much, from 100 to 350 m^3/ha.

The model permitted also an analysis of the impacts of including energy and material substitution effects in carbon benefits. That resulted commonly a 20% to 70% increase of present net value of carbon benefits (and in some cases up to 1,900%). Forest management activities were somewhat intensified, for example planting area was increased. A larger share of wood was harvested as sawtimber.

3 Discussion

The three studies reviewed share, at large, the same components to analyze the carbon pools and substitution effects. They differ markedly in the analysis setting in terms of method and baseline. Also the biological and resource utilization patterns differ. Common to all of them is that a baseline forestry is compared to alternatives that differ in their climate mitigation impacts.

The first two studies are based on management alternatives for individual stands. The increase in rotation length brings about opposing effects: In Pingoud et al. (2006), an increase in rotation length (relative to the baseline) leads to an increase in sawtimber yields but a decrease in pulpwood yield in most scenarios and, hence,

an increase in substitution effect being more pronounced for sawtimber than for energywood and pulpwood – or even negative for pulpwood, if paper could be replaced by a less-emission intensive substitute. In Perez-Garcia et al. (2005b), the outcome is different because the extensions in rotation are considerably larger, leading to significant decreases in fossil fuel displacement as bioenergy and to no change or a decrease in the amounts of structural wood products, and thereby decreases in the total mitigation effect. In the third study, rotations are generally lengthened due to increased weight on mitigation benefits (prolonged GHG emission at harvesting time and getting more timber for sawnwood) in the objective function.

Intensifying silviculture (investing more in management) relative to the baseline was favorable for mitigation in studies 1 and 3. Study 2 did not have an option to invest in more intense silviculture, but the option of postponing thinnings and increasing growing densities is quite analogous (because of additional capital investment in growing stock) and increased mitigation effect. The common outcome of the studies was that increased silvicultural input was beneficial to mitigation, given the baselines used. In Pingoud et al. (2006) maximization of the sawtimber yield appears to give the highest substitution impacts. However, the results could have been somewhat different, if pulpwood were used to produce wood-based panels for construction purposes. It is presumable that the maximum substitution impacts would then be obtained with a silviculture close to one where the total wood yield is at the maximum.

For the Nordic conditions and for both Scots pine and Norway spruce, Liski et al. (2001) report results from a 30-year shortening and lengthening of rotation from a 90-year baseline. For Norway spruce, the vegetation and product carbon pools increased with increasing rotation but it appeared that they would start to decrease some time after 120 years. On the contrary, soil carbon pools decreased significantly with increasing rotation because of strongly reduced litter flow to the soil. Due to uncertainties in soil carbon modeling, the authors overall recommended the longer rotations for climate change mitigation. As plot averages, the rotations in study 2 were 57, 77, and 97 years. For these, the results showed increasing avoided emissions with increasing rotation and were in agreement with findings by Liski et al. (2001).

The realized substitution effects also depend on the patterns of material utilization, namely which products are produced from wood. In the CORRIM study, small diameter wood and residues from sawmilling were used as short term products but not explicitly as pulp raw material. The share of wood products for building was considerably high, compared to the Nordic studies.

The increase of wood usage in wood framed houses, as compared to concrete or steel framed houses, affects the potential to increase wood use. In the CORRIM model houses, it was 20% and 97% while in the Nordic houses 40% and 350%. However, the avoided emissions relative to additional wood use do not necessarily depend on the amount of wood use increase. The Swedish house had a smaller increase of wood use but higher fossil emission reductions per ton of wood used, compared to the Finnish house.

Given the large impact of wood product use, taking into account the wood products in international climate conventions is an important question. As Niles and Schwarze (2001) note, material substitution and energy substitution are more viable long-term climate change strategies than is sequestration. Our results strongly support this conclusion.

The studies reviewed in this presentation represent boreal and moist temperate conditions. The impacts of changing the forest rotation depend on the chosen baseline. The relation between rotations that maximize (i) mean annual increment, (ii) present net value of timber returns, and (iii) climate change mitigation varies among biological and economic conditions. For example, the flow of carbon into soil is relatively inadequately assessed by current models, compared to above ground flows. Although the CORRIM study and the Petersen et al. (2004, 2005) study included models for soil carbon, the true effects of silvicultural alternatives in soil dynamics may modify the results obtained in these studies.

The integrated studies reviewed in this paper covered climate change impacts of forestry as well as energy and material substitution of wood products in boreal/temperate conditions. The impacts of wood products use significantly change the contribution of forestry to climate change mitigation: managed forests become more beneficial compared to unmanaged. Especially, production of long-lived wood products is an efficient way of mitigating climate change. This should be kept in mind when designing forest and environmental policies that direct the use of the renewable forest materials.

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